Multiscale Climatic Controls of Fire in the Western United States: From the Atmosphere to Ecosystems

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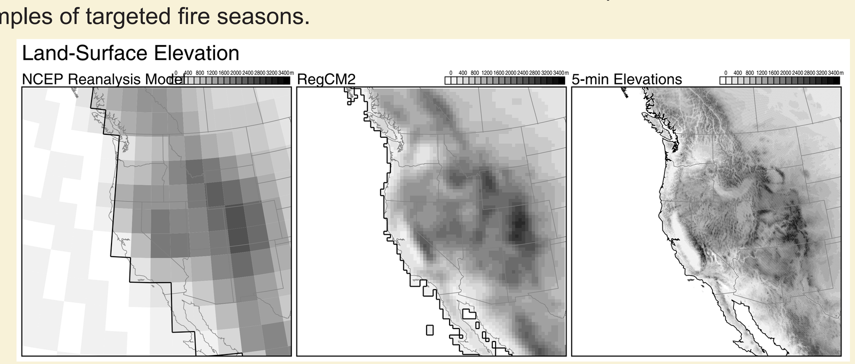
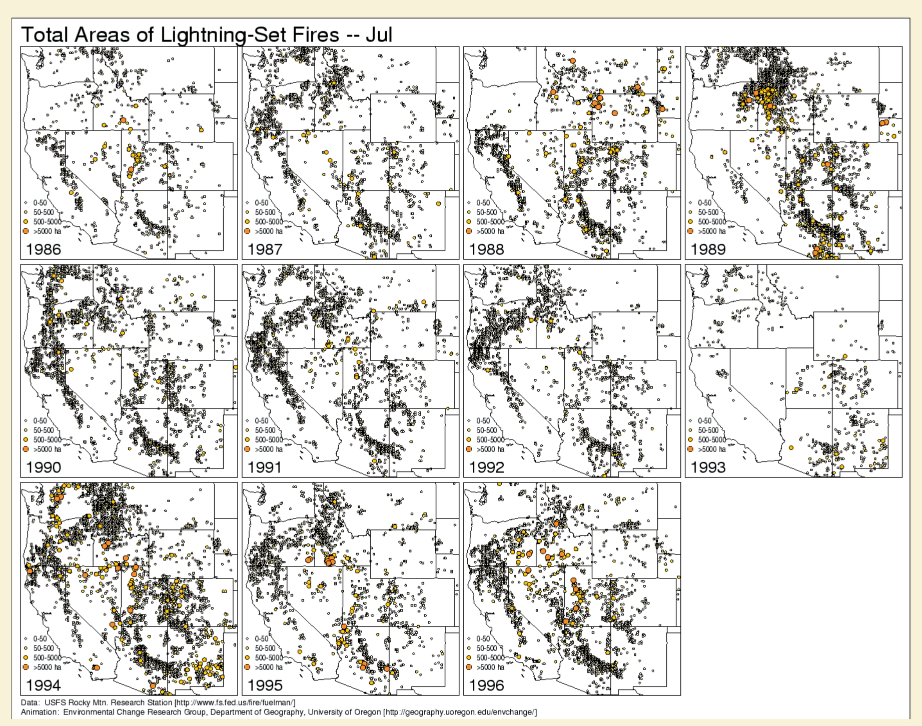
Introduction

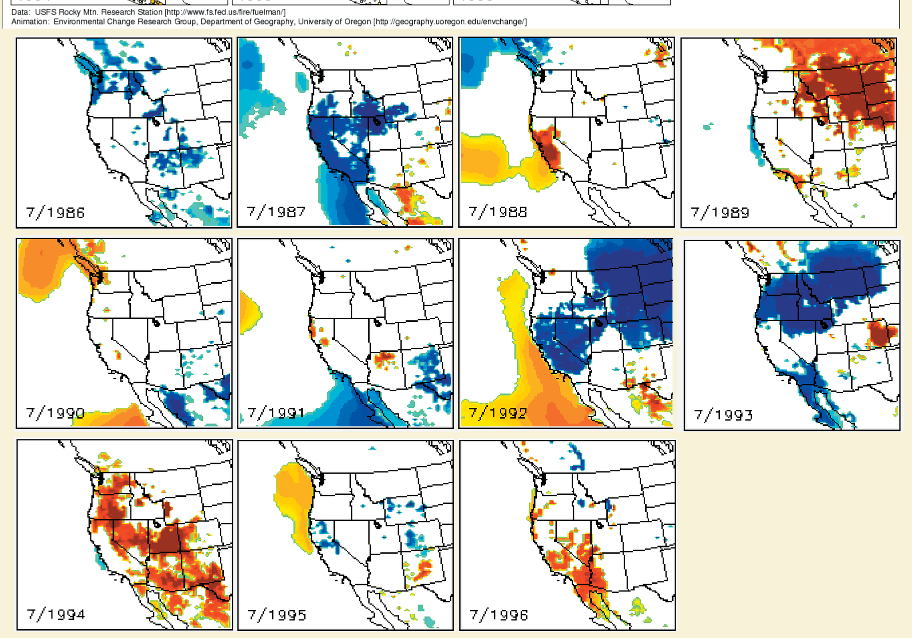
We are applying a retrospective approach that combines historical fire records and a hierarchy of climate model simulations to explore and quantify wildland fire-climate relationships in the western US. Regional to hemispheric scale atmospheric fields are derived from the National Center for Environmental Prediction (NCEP) reanalysis data produced by the NOAA/NCEP global atmospheric model. The NCEP model has a nominal horizontal grid spacing of 2.5 degrees (about 250 km on a side) and is capable of simulating large-scale synoptic climate features, but the relatively coarse spatial scale of the model limits regional detail over the mountainous West. Regional to subregional scale climate fields for the period 1957-2002 are being produced at higher resolution (36 km horizontal grid, ~1/3 degree) by a regional climate model (the NCAR RegCM, V.2) that is being driven by 6-hour boundary conditions derived from the NCEP reanalysis data. Together, the atmospheric models provide internally consistent climate information from the surface to the upper atmosphere over a wide range of spatial scales on time scales ranging from hourly to decadal. We are using a variety of visualization techniques and spatial data analyses to quantify the temporal and spatial atmospheric controls that affect wildfires. We expect our results to have direct applicability in terms of helping to assess season-ahead fire conditions. Here we demonstrate aspects of our research with case examples of targeted fire seasons.



Topography of western North America as represented in the NCEP global climate model (2.5 by 2.5 degree grid), the RegCM [36 by 36 km (~1/3 degree) grid], and on a 5-minute grid. The relative differences in the model topographies are indicative of the relative differences in the detail at which climate fields are simulated by the models. For example, convective storms have spatial scales that typically range from 30 to 50 km; these storms are resolved by the RegCM but not by the NCEP model in which they are subgrid in size.

Annual Fire and Climate

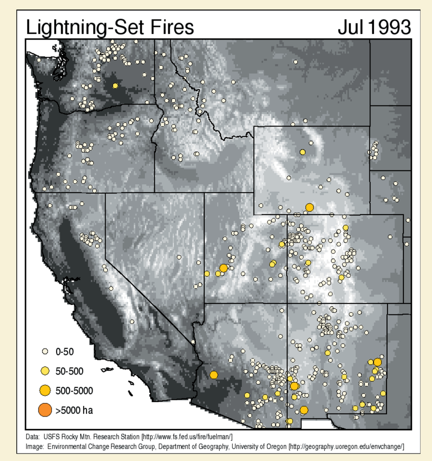


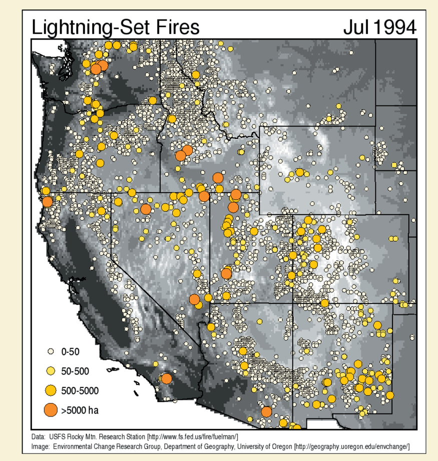


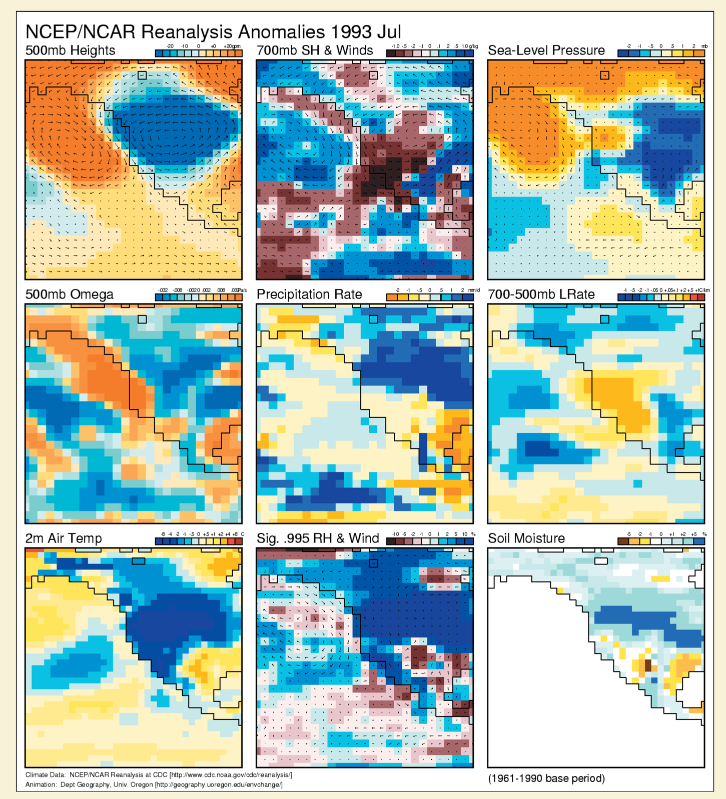
July air temperature anomalies as simulated by the RegCM. The anomalies range from 3^{o}C warmer (darkest red) to 3^{o}C colder (darkest blue) and are relative to the 16-yr average (1986-2001) of the RegCM simulations. Anomalies displayed exceed the variability of the model mean at the 90% confidence level.

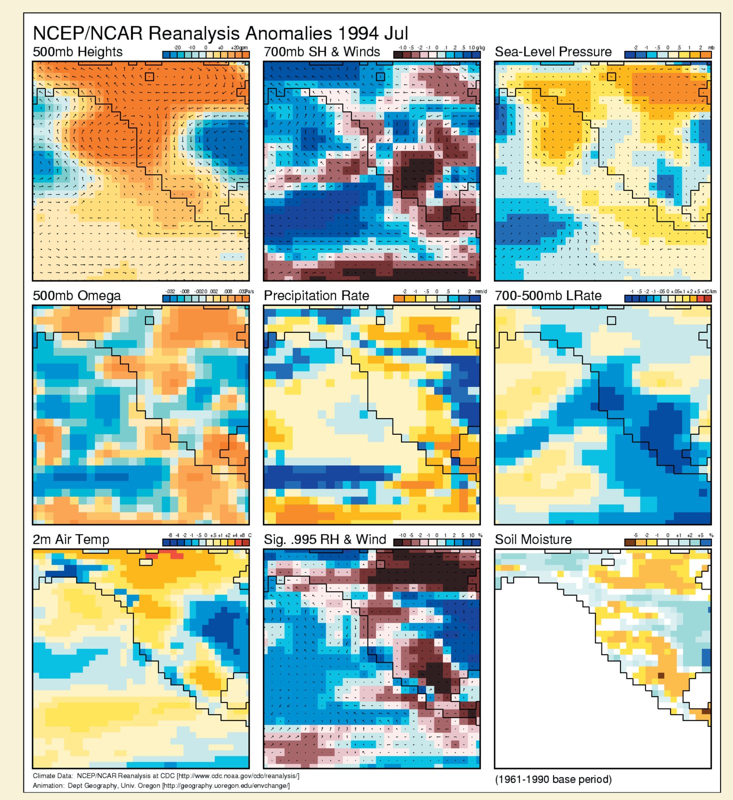
The location and size of lightning-set fires during July in the western US (upper) display a general year-to-year persistence that is overlain by substantial interannual variability. The persistence is in part due to the geographic distribution of ecosystems (see vegetation discussion to the right) and in part to underlying average climatic conditions associated with the coastline and topography of the region. Warm and cold air temperature anomalies are associated with some of the interannual variability of fires, but there are years when average temperature conditions are accompanied, for example, by greater-than-average fire activity. This suggests that favorable conditions for fire (e.g., fuel load and moisture levels) can exist under average temperature conditions and that additional atmospheric variables must play a role in controlling fire conditions.

Monthly Fire and Climate





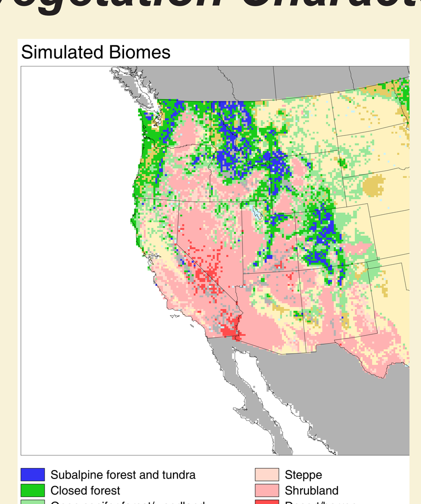


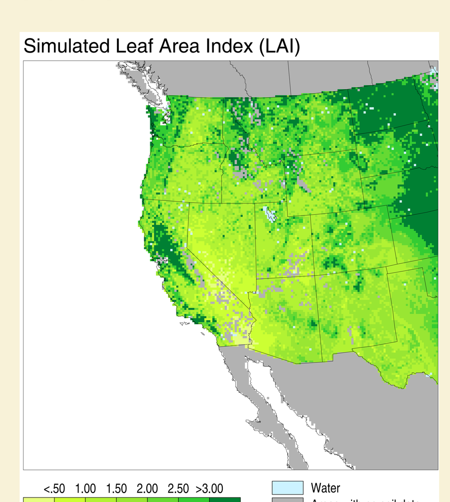


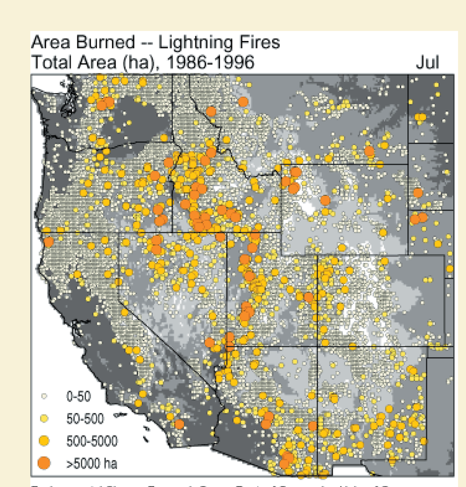
The potential explanatory power of fire occurrence by additional atmospheric variables is illustrated by comparing a generally low-fire year (1993) with a generally high-fire year (1994). In July 1993, anomalously low 500 mb heights (upper level trough) and sea level pressure persisted over much of the West. This pattern induced widespread rising motions in the atmosphere (negative values of omega), inhibited convective activity (700-500 mb lapse rate), and brought below normal temperatures, above normal precipitation, high relative humidity, and above normal soil moisture (a proxy for fuel moisture levels) that suppressed the outbreak of fire. The exception was in the Southwest where circulation associated with the pressure patterns caused general sinking motions in the atmosphere (adiabatic warming), which blocked the flow of monsoonal moisture, caused above normal temperatures and below normal precipitation, low relative humidity, below normal soil moisture, and relatively strong dry convection (700-500 mb lapse rates) resulting in a number of fires. In contrast, during July 1994, anomalously high 500 mb heights (upper level ridge) and sea level pressure persisted over much of the West. This pattern induced large-scale sinking motions in the atmosphere (adiabatic warming and drying), above normal temperatures, below normal precipitation, low relative humidity, and dry soil conditions. During this month, convective activity was anomalously high as indicated by the 700-500 mb lapse rate, and the combined circulation patterns resulted in a number of large fires throughout the West.

Monthly data allow us to establish relationships between climate fields and fire occurrence when comparing a particular month with long-term average conditions. The monthly time scale also is important when projecting possible fire conditions for a forthcoming season because 1) monthly anomaly patterns appear to correlate well with fire records, 2) persistence of circulation anomalies on a monthly time scale increases the likelihood that a given combination of atmospheric parameters will influence fire behavior, and 3) monthly analyses over a fire season may provide the right level of information on which to base management decisions.

Vegetation Characteristics

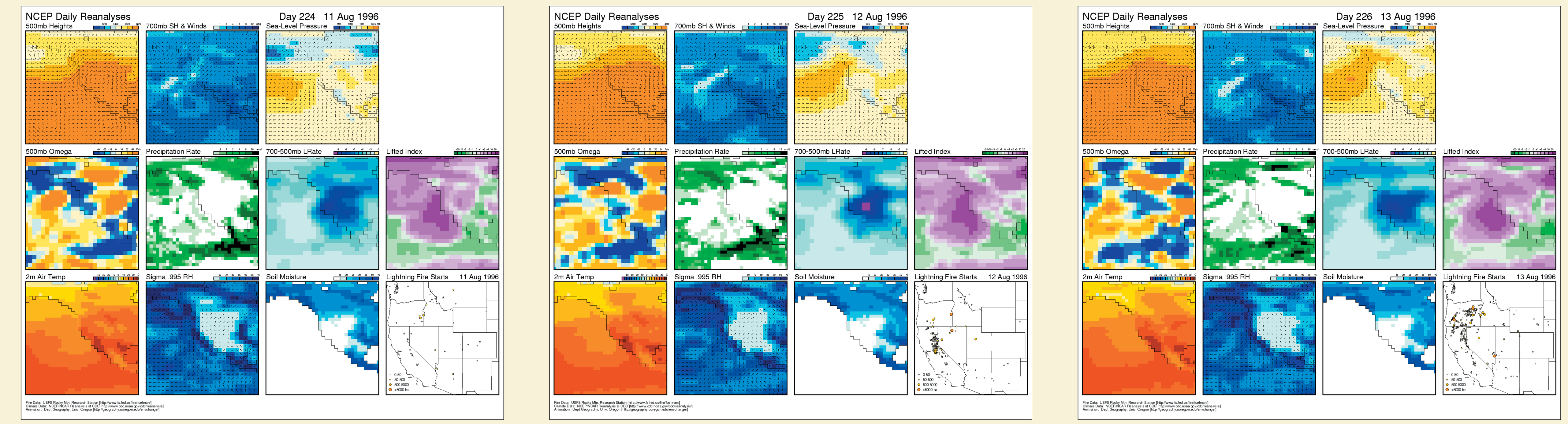


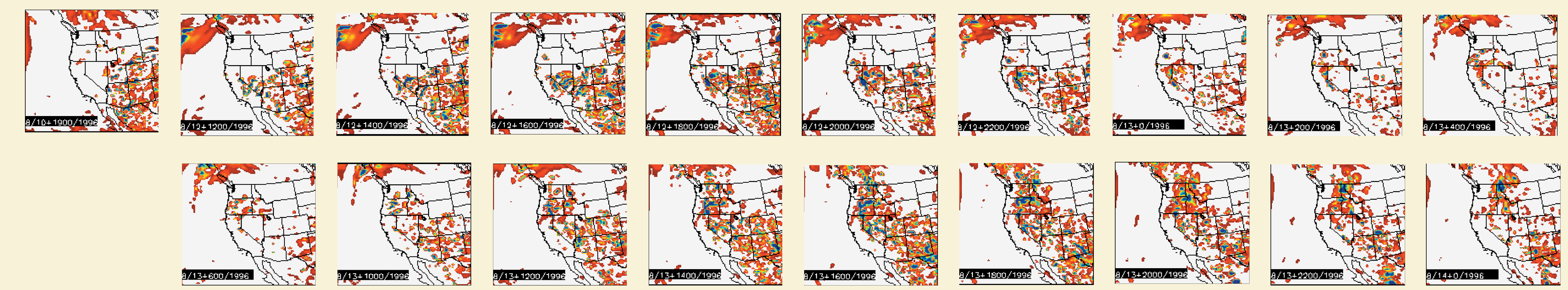




Biomes and Leaf Area Index (LAI) as simulated on a 15 km^2 grid by BIOME4, an equilibrium terrestrial biosphere model. Vegetation is dependent on climatic parameters (e.g., precipitation, temperature, solar radiation) and soils properties (e.g., rooting depth, moisture levels). Vegetation characteristics at varying temporal scales determine fire responses. The presence and absence of forests (biomes) are decadal characteristics; non-forest grass density (LAI) can influence fire potential in subsequent years. We are linking our RegCM climate simulations with BIOME4 and other vegetation models modified to account for these fire-related variables so we can integrate spatial patterns of fire history, fuel loading and associated ignition and spread tendencies in the context of climatic and weather conditions.

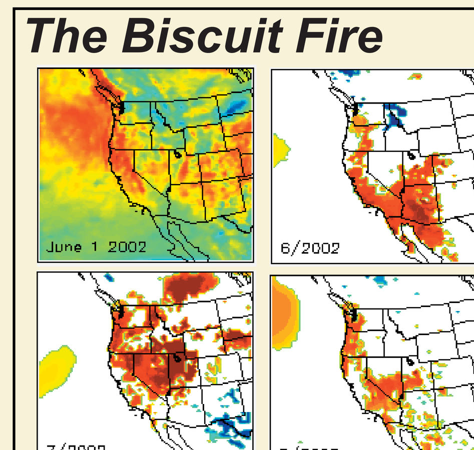
Daily and Hourly Fire and Climate



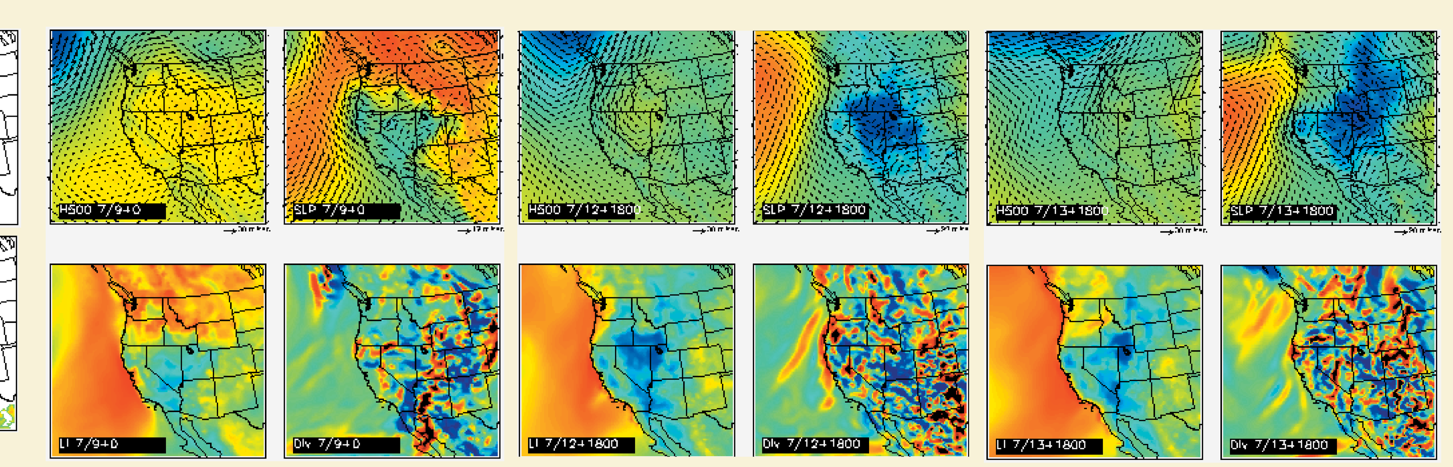


While monthly average anomaly patterns from the NCEP reanalysis convey necessary information, they do not provide specific climate and weather information at the spatial and temporal scale that is needed to investigate actual fire ignition and spread. To obtain this information, we combine patterns of daily atmospheric conditions from the NCEP reanalysis with daily, 6-hr, and hourly atmospheric fields simulated by the RegCM. In August of 1996, a month with a particularly high fire incidence, atmospheric circulation patterns led to a progression of fires that began over the central Sierra on the 10th and proceeded north through California, central and eastern Oregon and on into Idaho on the 13th. Fire activity in the region was low prior to this period. Between the 7th and 11th, a relatively weak upper-level trough developed in the Gulf of Alaska and moved eastward. This motion, and the circulation associated with the trough, resulted in a combination of atmospheric conditions that favored the outbreak of fire. The conditions included: a) generation of large-scale rising motions favoring uplift and convection [negative (blue) omega values], b) onshore flow of moisture in the middle and lower atmosphere (700 mb specific humidity and winds), which in turn favored c) development of relatively steep environmental lapse rates and abundant convection. On the 10th, a high pressure cell aloft broke off from the Subtropical high and moved inland over central California. By the 11th, the high migrated southwest and some fires were ignited in California, Oregon and Idaho by limited convection associated with wind flow around the high. On the 12th, the trough and ridge combination migrated farther to the southwest and, on the western side of the cell, caused southwesterly flow into the interior which induced vigorous convective storms. This pattern, a meridional ridge, draws marine air onshore at lower elevations, but is associated with very high fire danger at higher elevations in the Sierra and Siskiyou mountains. On the 13th, high pressure expanded to the north, resulting in more westerly flow across the northwest into the northern Rocky Mountains. The daily average NCEP reanalysis data clearly show the development of this pattern, along with intensification and migration of associated convective indices (700-500 mb lapse rates, and lifted index), but, due to model resolution, the NCEP precipitation fields show limited or no convection that can be associated with fire starts over the West. Although there may be lags between the time of a fire start and when the fire is reported, the temporal and spatial convective precipitation patterns associated with fire starts are well captured by a series of selected hourly outputs from the RegCM (lower maps) that display both the diurnal cycle and daily dynamics of convection for the period, including monsoonal activity over the Southwest. [Precipitation rates are displayed ranging from 0.01 mm/hr (dark red) to 1.0 mm/hr and greater (dark blue).] The modeled pattern of convection late in the day on August 10th captures the limited convective activity associated with scattered fire starts reported on the 11th. On the 12th and 13th, the simulated pattern of convection that begins over the central Sierra and progresses north and east is very clearly captured by the RegCM.

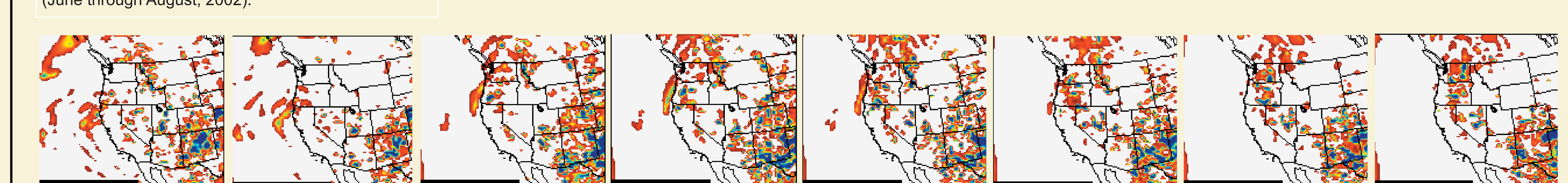
The Biscuit Fire



Clockwise from upper right: RegCM simulated anomalies of integrated precipitation (December, 2001 through May, 2002) and monthly air temperature (June through August, 2002).

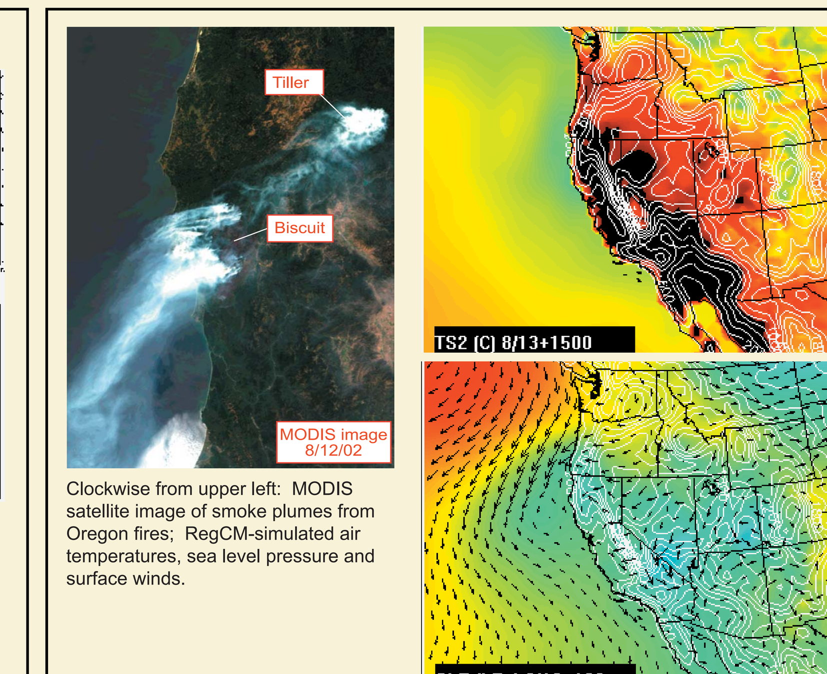


Atmospheric variables simulated by the RegCM for three selected days around the time of the start of the Biscuit fire. Each day has four panels which are, clockwise from the upper left: 500 mb heights and winds (H500, high red, low blue), sea level pressure and surface winds (SLP, high red, low blue), 700 mb moisture divergence (Div, divergence, red, convergence, blue), lifted index [LI, negative (convection) green to blue]



Convective precipitation simulated by the RegCM for selected hours on July 12 and 13, 2002. Values range from 0.01 mm/hr (dark red) to 1.0 mm/hr (dark blue).

Our RegCM runs are current through September of 2002 which allows us to provide a preliminary assessment of the Biscuit fire in Oregon. We hypothesize that the fire, started by lightning between 1300 and 1700 hours on July 13, was the result of both near-term and antecedent atmospheric conditions that originated more than a year prior to the fire. Accumulated precipitation in southwest Oregon and northern California was substantially below normal on June 1, 2002. In fact, with the exception of a few months, the area had received below normal precipitation since the spring of 2001 as a result of anomalous circulation patterns that diverted and blocked precipitation-barring Pacific storms. A moisture deficit must have existed in small fuels, but, more importantly, moisture deficit in large (1000 hr) fuels made the region particularly vulnerable to large, hot fires. In general, 2002 was a very warm summer over the West. Widespread record high temperatures were set during July; both July and August temperatures were well above normal over northern California and southwest Oregon. (Note anomalously warm conditions that existed over the Southwest in June.) During the week preceding the start of the fire (e.g., July 7 above), a ridge aloft (H500) dominated the West and high surface pressure (SLP) associated with the Subtropical high migrated into the Pacific Northwest. The ridge and surface pressure pattern produced strong, hot, and dry easterly surface winds that originated east of the Cascades. This pattern of easterly winds is associated with extreme fire danger in western Oregon. On July 12 and 13, a trough formed aloft off the coast of the Oregon and California coast (H500), resulting in moist, southwesterly wind flow over southwestern Oregon. The advection of moisture led to atmospheric instability (strong divergence in the lower troposphere, Div), strong convection over southwest Oregon and northward along the Cascades (lower convective maps), and the ignition of many fires. In addition to the Biscuit (Florence) fire, the Umpqua National Forest office reported 115 lightning-caused fires were set from late July 12 through July 13. One fire complex (Tiller) subsequently spread to over 30,000 acres. Once set, hot temperatures and periods of easterly winds during the remainder of July and August favored the spread of the Biscuit fire which ultimately burned 500,000 acres.



Clockwise from upper left: MODIS satellite image of smoke plumes from Oregon fires; RegCM-simulated air temperatures, sea level pressure and surface winds.

August 12 and 13 were very hot days in western Oregon. Temperatures reached 42^{o} C (108^{o} F) in Corvallis on the 13th as a result of a thermal low originating in the central valley of California and the presence of high pressure east of the Cascades. During the morning of the 13th, at coastal Newport, temperatures reached 37^{o} C (99^{o} F) under the influence of offshore winds, but dropped to 20^{o} C (68^{o} F) in the early afternoon when the east-west pressure gradient diminished and the usual northerly wind pattern resumed. These are the most dangerous fire conditions that exist in western Oregon. The RegCM simulated pressure patterns and wind vectors are in very good agreement with satellite images of the smoke plumes from the fires.

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